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ABSTRACT

Evidence from the research literature suggests that a variety of cognitive factors are responsible for chemistry achievement. This investigation examined the role that four cognitive factors, namely, prior knowledge, formal reasoning ability, memory capacity and field independence/dependence, play on achievement in chemistry as measured by tests of laboratory application, chemical calculations, and content knowledge. The sample was comprised of grade 11 students from 11 high schools who were following the same chemistry syllabus. Correlational analysis, multiple regression analysis and path analysis were performed on the data and all produced similar results. Prior knowledge and formal reasoning ability were each statistically significantly related to variation in chemistry achievement. Field dependence/independence and memory capacity played no significant role in chemistry achievement. The educational implications of these results were discussed. (Author/TW)

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THE ROLE OF COGNITIVE FACTORS IN CHEMISTRY ACHIEVEMENT

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Abstract

Evidence from the research literature suggests that a variety of cognitive factors is responsible for chemistry achievement. This investigation examined the role that four cognitive factors, namely, prior knowledge, formal reasoning ability, memory capacity and field independence/dependence, play on achievement in chemistry as measured by tests of laboratory application, chemical calculations and content knowledge. The sample comprised grade 11 students from eleven high schools who were following the same chemistry syllabus. Correlational analysis, multiple regression analysis and path analysis were performed on the data and all produced similar results. Prior knowledge and formal reasoning ability were each statistically significantly related to variation in chemistry achievement. Field dependence/independence and memory capacity played no significant role in chemistry achievement. The educational implications of these results are discussed.

THE ROLE OF COGNITIVE FACTORS IN CHEMISTRY ACHIEVEMENT

Introduction

In the past decade research in science education has highlighted the importance of cognitive factors as variables influencing science achievement. Although there has been some controversy on the relative importance of variables such as prior knowledge and formal reasoning ability there is a growing realization that a range of different variables need to be considered by researchers and practitioners. The focus of this investigation was related to achievement in chemistry in senior high school and the role played by such cognitive factors as prior knowledge, formal reasoning ability, memory capacity and field dependence/independence. The attention to these variables is based on practical considerations in terms of the chemistry syllabus taught in the state of Western Australia as well as documented research in the literature. In Western Australia students are selected for upper school chemistry (grades 11 and 12) on the basis of their performance in lower school science (grade 8 to 10). The aims of the upper school chemistry course emphasize that students should be able to: apply fundamental facts and principles; use appropriate conceptual and theoretical frameworks; perform chemical calculations using the mole concept; and demonstrate competence in process skills (The Board of Secondary Education, 1981, p.65). It can be expected that mastery of these skills requires a range of cognitive skills in addition to a sound knowledge of lower school chemistry.

There is adequate justification for examining the relationship between cognitive factors and student achievement in science. While most studies have tended to focus on a single cognitive factor, two recent studies by Lawson (1983) and Niaz and Lawson (1985) considered the extent to which factors such as developmental level, disembedding ability, prior knowledge

and memory capacity could be used to predict achievement in undergraduate biology and chemistry classes respectively. The approach used by Lawson (1983) provided the impetus for this investigation which was conducted with upper secondary chemistry students. Consequently, variables selected for inclusion in this study were formal reasoning ability, memory capacity, prior knowledge and field dependence/independence. The variables included were based on research evidence cited in the literature.

Positive linear relationships between formal reasoning ability and chemistry achievement have been described by a number of authors (e.g. Ingle and Shayer, 1971; Krajack and Hanley, 1984). More general studies by Cantu and Herron (1978) and by Kavannaugh and Moomaw (1981) also support this relationship.

Ausubel's (1967) concept of meaningful verbal learning which has gained wide currency stresses the importance of prior knowledge as the most important single factor influencing learning (Novak 1978, 1980a, 1980b). Emphasis is placed on the comprehension of concepts and the inter-relations among concepts; as links between prior knowledge and new knowledge are established, meaningful learning is said to occur. The implication is that students with the appropriate prior knowledge will be able to comprehend more and achieve better. Therefore, the relationship between prior knowledge and chemistry achievement is worthy of investigation.

Studies by Saarni (1973) and by Witkin, Moore, Goodenough, and Cos (1977) have indicated that field independence, the ability to disembed relevant information from an irrelevant background, contributes significantly to achievement in science, mathematics, engineering and architecture. Witkin (1954) found cognitive style to be stable even in the face of deliberate

attempts to make a change. As chemistry requires the ability to be analytical, by locating and extracting data from problem solving tasks, tables, graphs, etc., it is reasonable to expect field independence to influence achievement in chemistry.

Memory capacity is also likely to greatly effect achievement in chemistry. The early work by Miller (1956) showed that memory span was a fixed number of "chunks" but that the information stored in memory for immediate recall could be increased by building larger and larger chunks. Hence, the way the material is organized into chunks largely determines the capacity for immediate memory. Miller's (1956) work has had a great effect upon the approaches of psychologists to organization in memory. Pascual-Leone (1970) introduced the concept of memory capacity which increases during a child's normal development. In brief, the memory capacity is the number of schemes a person can keep activated simultaneously. It follows that the greater the number of schemes which a student can readily use to assist in the comprehension of subject matter in chemistry, the higher will be the achievement. In a study which examined secondary students' conceptual understanding of organic chemistry, Kellett (1979) reported that those students with a high level of conceptual understanding were able to chunk more effectively and more selectively.

The Purpose

The problem addressed in this research was to examine the relative influence and contribution of four cognitive variables on chemistry achievement. Controversy exists in the literature regarding the relative importance of these variables and the role they play in student understanding and hence in achievement. While some researchers claim that formal reasoning ability is the most important variable in determining achievement, others claim that prior knowledge is the most important

variable. Research evidence also indicates the existence of relationships between chemistry achievement and memory capacity and between chemistry achievement and field independence/dependence. Subsequently, this study investigated these relationships and examined the role of the four cognitive predictor variables of formal reasoning ability, memory capacity, prior knowledge and field dependence/independence on achievement in chemistry.

Procedures and Instrumentation

Measures of the four cognitive predictor variables were obtained when students initially enrolled in the grade 11 chemistry course at the beginning of the school year. Tests in three areas of chemistry achievement (chemical calculations, laboratory applications and chemistry content knowledge) were administered towards the end of a period of 21 weeks of teaching. The four cognitive predictor variables were measured using standardized instruments described in the literature. Details of the instruments are summarized in Table 1.

/Insert Table 1 about here/

Cognitive Predictor Variables

Formal reasoning ability. The Test of Logical Thinking (TOLT) developed by Tobin and Capie (1981) was administered early in first term. The TOLT is a group paper and pencil test consisting of 10 items based on five reasoning modes, viz., proportional reasoning, controlling variables, correlational reasoning, probabilistic reasoning and combinatorial reasoning. For each item, the subject is required to select one response from a set of alternatives as well as a reason from a set of alternatives. The internal consistency reliability for the TOLT measures used in this study was 0.85.

Field dependence/independence. Subjects' ability to disembed relevant

information from an irrelevant background was assessed by means of the Hidden Figures Test (Educational Testing Service, 1966). This is a timed test in which the subjects' task was to locate and outline simple figures concealed in complex ones. An internal consistency reliability coefficient of 0.91 was obtained for the measures used in this study.

Prior knowledge. A 20 item, multiple choice test was used to assess prior knowledge in chemistry. An initial set of 35 items were obtained from the Science Item Bank (Australian Council of Educational Research, 1978), and 20 items were selected by local chemistry teachers based upon the item's appropriateness for the purpose of the investigation and their representativeness of lower school chemistry. An internal consistency reliability coefficient of 0.87 was obtained for the prior knowledge measures used in this study. Three of the items, illustrative of the other 20 items, representative of the lower school chemistry syllabus, and having a sequential link with upper school chemistry, are described below.

- Which one of the following formulas is not correct?

  1. Al_2CO_3
  2. $CuSO_4$
  3. $Mg_3(PO_4)_2$
  4. Na_2SO_4

- The mass of one mole of potassium bromide is 119.0 g. What is the mass of 0.100 moles of potassium bromide?

- Which one of the following statements does not apply to 1 mole of hydrogen molecules? (Relative atomic mass of hydrogen = 1)

  1. 1 mole of hydrogen molecules has a mass of 1 g.
  2. 1 mole of hydrogen molecules contains 6.02×10^{23} molecules.
  3. 1 mole of hydrogen molecules occupies 22.4 litres of volume at 0°C and 1 atm.
  4. 1 mole of hydrogen molecules contains 12.04×10^{23} atoms.

The test-retest reliability when administered to a sample of 21 grade 11 students was found to be 0.65, indicating the relative stability of interest.

Memory capacity: The Figural Intersection Test (FIT: Burtis and Pascual-Leone, 1974) was used to measure memory capacity. The FIT is a group test

which consists of 42 items. For each item, the subject must place a point marking the intersection of from two to eight overlapping figures. An item with eight overlapping figures requires a memory capacity of seven for successful completion, while an item with seven overlapping figures requires a memory capacity of six and so on (Bereiter and Scardamalia, 1979). A reliability coefficient was not calculated for the sample in this study as more than 90% of the subjects obtained the maximum score. Because of the lack of variability, the reliability coefficient of the measures would have been close to zero.

Achievement Variables

To assess achievement in chemistry, three tests developed by Chandran (1985) were administered towards the end of second term; the three tests examined laboratory application, chemical calculations, and content knowledge.

Laboratory Application. This 21 item completion test was group validated by science staff from a metropolitan high school; responses provided to the items by all teachers were in 100% agreement. Students were provided with an opportunity to observe a chemical reaction and answer questions related to four aspects of laboratory application, viz., observation, reasoning, use of equations, hypothesizing and predicting. An internal consistency reliability coefficient of 0.86 was obtained for the measures used in this study.

> The Laboratory Application Test involved a demonstration using the following materials: a pale green powder; lime water; a bent glass tubing; two test tubes, a test-tube holder or a stand; a one-holed rubber stopper; a bunsen burner, tripod and gauze-mat set; dilute sulfuric acid; a clean iron nail; a beaker; matches. Questions asked on the demonstration were:
>
> 1. What change occured to lime water as the test tube was heated?
> 2. What change occured to the powder as the test tube was heater?
> 3. What did you notice when the heated powder was dissolved in dilute sulfuric acid?
> 4. What happened to the iron nail when it was kept in the acid solution for a minute or so?

5. What is the reason for the change in lime water?
6. What is the reason for the change in the pale green powder?
7. What could be the chemical name of the solution formed when sulfuric acid reacted with the heated powder? Why do you think so?
8. What was the substance that was formed on the iron nail? Why do you think so?
9. What gas was produced when the page green powder was heated?
10. Comparing your answers to questions 8 and 9, what do you think is the chemical name of the green powder?
11. Write a word equation to show what happened to the green powder when it was heated? (Use the chemical name you figured out in question 10.)
12. Write a word equation to show what happened to lime water?
13. Write a word equation to show the reaction between the heated powder and sulfuric acid.
14. Rewrite the word equation you wrote for question 11 using formulas.
15. Rewrite the word equation you wrote for question 12 using formulas.
16. Rewrite the word equation you wrote for question 13 using formulas.
17. Write balanced equations to show what would happen when the following substances are heated?
    $MgCO_3$ $ZnCO_3$ $FeCl_2$ NH_4Cl
18. What is the chemical reaction you can expect when a metallic carbonate is heated?

Chemical Calculations. The chemical calculation test consisted of two problems, one based on percentage composition and the other on stoichiometric reasoning. The chemical calculation measures used in this study had an internal consistency reliability of 0.59. The comparatively low value is most likely due to the relatively short length of the test. The two problems were as follows.

Problem 1. Two large iron ore deposits have been found within 20 kms of each. The first deposit is known to contain 40% of haematite (Fe_2O_3). What mass of the ore body should be dug out from the earth to obtain 300 tonnes (1 tonne = 1000 kg) of iron?

The second ore body is estimated to contain 400 tonnes of iron from an ore body mass of 1600 tonnes. Assuming all other requirements for ore treatment and transport are equal, which deposit is economically more viable? (Relative atomic masses of iron, Fe = 56 and oxygen, O = 16)

Problem 2. Metallic copper reacts with concentrated sulfuric acid acording to the following equation:

$$Cu + 2H_2SO_4 \longrightarrow CuSO_4 + SO_2 + 2H_2O$$

a) Assuming that sulfuric acid is in excess, what mass of copper sulfate and water are produced when 12.7 g of copper is used up

in the reaction?

b) Assuming that sulfuric acid is in excess, what mass of copper is required to produce 5.6 L of sulfur dioxide at S.T.P.?

c) Assuming that copper is in excess, what mass of sulfuric acid is required to produce 36 mL of liquid water?

d) If 400 g of sulfuric acid and 127 g of copper react together which reactant is in excess and by how much?

(Relative atomic masses: copper, Cu = 63.5; sulfur, S = 32 and hydrogen, H = 1)

(One mole of any gas at zero degree Celsius and one atmospheric pressure of 101.3 kPa occupies a volume of 22.4 L.)

Content Knowledge. The multiple-choice content knowledge test consisted of 20 items from an initial selection of 43 items taken from the ACER (1981a,b) Chemistry Test Item Collection. Items were selected on the basis of their degree of difficulty, and their congruence with the content covered in the chemistry course to that point in time. Aspects of the chemistry course examined were the mole concept, laboratory procedures, kinetic theory, periodic table and formula and equations. The internal consistency reliability coefficient for the content knowledge measures used in this study was 0.84. Typical examples of items on the Content Knowledge Test were:

1. Sodium reacts with water according to the equation

$$2Na(s) + 2H_2O(1) \longrightarrow 2NaOH(aq) + H_2(g)$$

In a certain experiment, 0.2 mole of sodium reacts completely with water. The number of moles of NaOH formed is

1. 0.1
2. 0.2
3. 0.4
4. 2.0

9. The following table refers to the question below.

Substance	Melting point deg.Cel	Boiling point deg.Cel	Solubility at 20 deg.Cel
Lead (II) iodide	300	--	0.068
Ether	-116	35	miscible in water
Iron (III)	319	--	50

For a mixture of iron (II) chloride and lead (II) iodide, select from the following key the separation technique which best satisfies both these criteria:

- it is easy to perform in the laboratory, and
- it gives the best yield of the substance.

1. Dissolve in water, filter and crystallize by evaporation.
2. Fractionally distil and collect the distillate.
3. Evaporate, allow the vapour to crystallize and collect the crystals.
4. Filter and collect either the filtrate or the residue.
5. None of 1, 2, 3 or 4.

11. A student wants to measure the amount of heat evolved when a mole of salt is dissolved in water. Arrange the steps below in the proper order in which he should carry out his experiment.

1. Add salt to water and stir well to dissolve the salt.
2. Calculate the heat of solution per mole of salt.
3. Determine the change in temperature.
4. Measure the temperature of water.
5. Record the temperature of the solution.
6. Weight the salt to be dissolved and calculate the number of moles of salt.

1. 6, 4, 5, 3, 1, 2
2. 6, 4, 5, 1, 3, 2
3. 6, 4, 1, 5, 3, 2
4, 6, 1, 4, 5, 3, 2

Sample

Fourteen high schools from the Perth metropolitan area were contacted and eleven consented to participate in the investigation. Four schools were non-government (one coeducational school, two boys' schools and one girls' school); seven schools were coeducational government high schools. The number of students participating from the 11 schools ranged from 19 to 63 with a total ranging from 275 to 367 completing the instruments. All

students studied a chemistry course which followed the Western Australian syllabus, though different text books were often used. All students were in grade 11 with an average age of 15 years and 6 months.

Statistical Procedures

Three statistical procedures were used to analyse the data: A product-moment correlational analysis, a multiple regression analysis, and a path analysis. Product moment correlations were calculated as a measure of the strength and the direction of the relationship between the predictor and achievement variables. The amount of variance accounted for by a linear combination of the four predictor variables and the variance attributable to each of the achievement variables were determined by multiple regression analyses, one each for the laboratory application, chemical calculation and content knowledge achievement measures. Standardized regression coefficients were represented as path coefficients in a path analysis for each of the three dependent variables with the cognitive predictor variables. The data used in this analysis were pooled over the schools participating in the study.

Results

Descriptive Statistics

The mean and standard deviation for each of the four predictor and three achievement variables are reported in Table 1. On the prior knowledge test, approximately 3% of the subjects received a zero score and approximately 90% received scores from 11 to 19. On the Figural Intersection Test, used to assess memory capacity, 90 percent of the subjects obtained the maximum possible score of 7 with the remaining 10 percent scoring from 0 to 6. For the level of field dependence/independence, using the quartile technique described by Douglas and Kahle (1977), the upper quartile of the sample were classified as field

independent, with scores 18 or more, and the lower quartile of the sample were classified as field dependent with scores less than or equal to 7. Those students with scores between 7 and 18 were classified as field unclear or field intermediate. On the Test of Logical Thinking, 90% of the subjects scored 3 and above and were classified as having some degree of formal reasoning ability. There was a 94% return of data from the participating students.

Correlational Analysis

Table 2 shows intercorrelations of the four predictor variables and the three measures of chemistry achievement. The product moment correlations indicated that formal reasoning ability was statistically significantly related ($p<0.001$) to prior knowledge ($r = 0.32$), field dependence/independence ($r = 0.32$) and memory capacity ($r = 0.20$). Other correlations between the predictor variables were not statistically significant at this level ($p>0.001$). Each of the chemistry achievement variables was significantly correlated with the others ($p<0.001$) in the range 0.30 to 0.44.

/Insert Table 2 about here/

Formal reasoning ability correlated significantly ($p<0.001$) with the achievement measures of laboratory application ($r = 0.36$), chemical calculations ($r = 0.41$), and content knowledge ($r = 0.38$). Prior knowledge correlated significantly ($p<0.001$) with laboratory application ($r = 0.26$), chemical calculations ($r = 0.21$) and content knowledge ($r = 0.23$). The remaining correlations were not statistically significant at this level ($p>0.001$).

Multiple Regression Analysis

The results of the three multiple regression analyses are presented in

Table 3. The results indicated that prior knowledge and formal reasoning ability accounted for a statistically significant proportion of the variance in each of the three chemistry achievement variables when variation in field dependence and memory capacity were conjointly considered. The proportion of the variance attributable to the four cognitive variables was less than 20% in each case.

/Insert Table 3 about here/

Path Analysis

The results in Table 3 can be used to construct a path diagram that depicts the hypothesized relationships between formal reasoning ability, prior knowledge and the three chemistry achievement variables. The three diagrams contained in Figure 1 show that formal reasoning ability has a direct effect on chemistry achievement and an indirect effect through prior knowledge. In each case the indirect effect is much less than the direct effect and has little practical importance.

/Insert Figure 1 about here/

Discussion

The three types of statistical analyses produced similar results: prior knowledge and formal reasoning ability are each related to variation in chemistry achievement. The data in Table 3 provide support for the hypothesis that formal reasoning ability is a significant predictor of chemistry achievement. This appears to be consistent with the findings of Ingle & Shayer (1971), Kavannaugh and Moomaw (1981), Lawson and Renner (1975) and Shayer and Adey (1982). The finding that prior knowledge is also a significant predictor of achievement in chemistry is consistent with the Ausubelian (Ausubel, 1963) model of learning supported by Novak (1978,

1980a, 1980b). The lack of any observed relationship between memory capacity and the achievement variables could perhaps be due to the lack of variation in student performance in the Figural Intersection Test. The lack of any observed relationship between field dependence/independence and the achievement variables was surprising since disembedding ability was expected to contribute to achievement in chemistry.

When comparing the relative contribution to achievement in chemistry between formal reasoning ability and prior knowledge, these results suggest that in this study variation in formal reasoning ability, by virtue of greater path coefficients and an indirect as well as direct effect, has a greater effect on each of the three chemistry achievement variables than prior knowledge. However, a cautionary note is advisable with comparative results of this type; it is possible that stronger path coefficients could be obtained for the prior knowledge variable with a different test of prior knowledge.

A limitation of this study was the non causal design that was utilized. The results highlight relationships between variables designated as predictor and achievement. Because of the design that was employed it is not possible to proceed from the statistical outcomes to a statement that variation within one or more variables in the predictor set is causing the observed variation in one or more variables in the set of achievement variables. However, on logical and theoretical grounds the results of this study can be seen to support the generalized hypotheses that one or more of the predictor variables affect chemistry achievement as measured by the set of achievement variables. The results of this study are also consistent with the results of other recent investigations (e.g. Lawson, 1983; Niaz and Lawson, 1985).

The sample used in this investigation was homogeneous with respect to science ability because the students had elected to study chemistry. Consequently, the sample represented a population of students who were likely to succeed at chemistry rather than a population of all students. Presumably the variation in memory capacity, field independence/dependence and chemistry achievement would be much greater in the population of all 16 year old students. Further research on the relationship between memory capacity and chemistry achievement should utilize a sample in which the hypothesis of a positive relationship can be tested with sufficient statistical power.

There are two main implications of this finding. First, teachers need to be aware that cognitive limitations of learners will tend to inhibit chemistry achievement for many high school students. Since it is difficult to appreciably increase formal reasoning ability within the period of a school year, the abstract concepts frequently encountered in chemistry courses may have to be introduced in a concrete way in order to enhance achievement opportunities for all students. Research reported by Herron (1975) and Staver & Halsted (1984) provide grounds for an optimism that students can achieve at a higher level with the assistance of concrete exemplars of abstract concepts. Nevertheless, the use of concrete examples is not necessarily the best interpretation of these data. In this study, those students with lower levels of formal reasoning ability were obtaining correct responses on three or four formal reasoning items. Consequently, since these students have a demonstrated ability to use formal reasoning, they will not necessarily be reliant on the use of concrete materials as is often recommended.

Different teaching methodologies are probably needed for those students who

have lower levels of formal reasoning ability. In this study, the teachers taught students in whole class settings rather than presenting individualized tasks. Consequently only a few students could actively participate in the learning situation. Recent studies (see for example, Tobin & Gallagher, 1985) have shown that those students who do participate in whole class settings tend to be the high formal thinker). Similarly, Tobin & Gallagher (1985) showed that target students were those with the higher knowledge. In this study, those students with high prior knowledge obtain higher chemistry scores too. The implications for science education are that in order to cater for the needs of the low formal thinkers and those with less knowledge, science teachers should endeavour to engage students in individualized tasks and in small group work so that all students have an equal opportunity to participate.

The second implication of the findings of this study is that prior knowledge was statistically significantly related to the chemistry achievement measures when variation in formal reasoning ability was considered. This result raises the possibility that chemistry achievement levels can be enhanced for all learners by ensuring that essential prerequisite knowledge is known before new information is introduced. The use of mastery learning, diagnostic prescriptive learning and self paced approaches, as described in the meta analyses by Yeany and Miller (1983), should be considered by teachers as a means of ensuring that progression through the academic work is governed by the learning needs of students rather than external concerns such as a need to cover the syllabus in a fixed amount of time.

This investigation was unable to examine the effects of memory capacity and field independence/dependence in a satisfactory manner because of the relative lack of variability in scores for memory capacity and field

dependence/independence. Different cognitive measures of these variables are required for research involving samples such as the one which participated in this study in order to overcome these problems. The problem was most acute in the case of memory capacity which, on theoretical grounds, ought to be related to chemistry achievement. Additional research is recommended, provided that more suitable instruments or techniques can be used to measure field independence/dependence and memory capacity.

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TABLE 1

Descriptive Statistics for Predictor and Achievement Variables

Together with Reliability Measures

Cognitive Variables	Instrument	Sample Size	Mean	Standard Deviation	Maximum Score Possible
Prior Knowledge	Test on Prior Chemistry Knowledge	367	14.4	2.4	20
Field Independence/ Dependence	Hidden Figures Test	344	13.9	7.3	32
Formal Reasoning Ability	Test of Logical Thinking	346	7.3	2.5	10
Memory Capacity	Figural Intersection Test	324	6.8	0.7	7
Achievement	Laboratory Application Test	324	14.2	4.7	21
Achievement	Content Knowledge Test	280	10.1	3.3	20
Achievement	Chemical Calculations	275	5.1	3.1	12

TABLE 2

Correlation Between the Predictor and Achievement Variables

	Predictor Variables				Achievement Variables		
	Prior Knowledge	Field Indep/Dependence	Formal Reasoning Ability	Memory Capacity	Laboratory Application	Content Knowledge	Chemical Calculation
Prior Knowledge	1.0	0.11	0.32*	0.07	0.26*	0.23*	0.21*
Field Indep/Dependence		1.0	0.32*	0.18	0.04	0.16	0.08
Formal Reasoning Ability			1.0	0.20*	0.36*	0.38*	0.41*
Memory Capacity				1.0	0.05	0.07	0.06
Laboratory Application					1.0	0.30*	0.35*
Content Knowledge						1.0	0.44*
Chemical Calculation							1.0

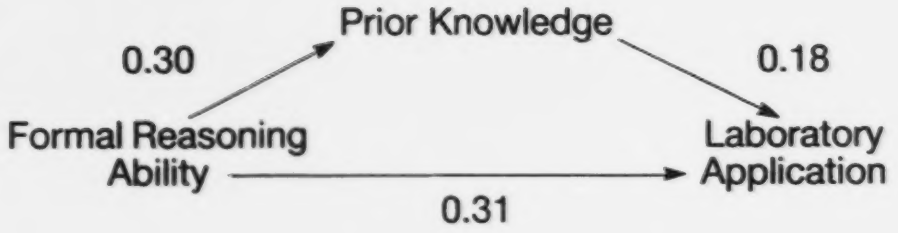
*$p<0.001$

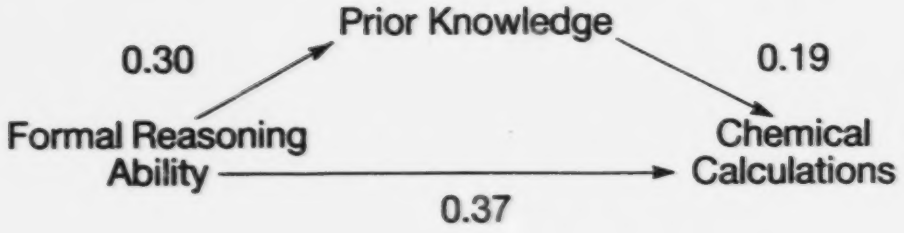
TABLE 3

A Regression Analysis of Chemistry Achievement Variables on Four Cognitive Predictor Variables for Year 11 Chemistry Students

Chemistry Achievement	Predictor Variables		Mean Square	df	F
Laboratory Application	Prior Knowledge	0.42	225.60	1	11.85***
	Field Dependence	-0.02	5.40	1	0.28
	Formal Reasoning Ability	0.58	362.50	1	19.03***
	Memory Capacity	0.09	1.11	1	0.06
	Error		19.05	235	
$R^2 = 0.16$					
Chemical Calculations	Prior Knowledge	0.22	66.12	1	7.20*
	Field Dependence	-0.02	10.57	1	1.15
	Formal Reasoning Ability	0.55	347.32	1	37.84***
	Memory Capacity	-0.11	1.60	1	0.17
	Error		9.17	262	
$R^2 = 0.19$					
Content Knowledge	Prior Knowledge	0.20	47.99	1	5.13*
	Field Dependence	0.02	5.13	1	0.55
	Formal Reasoning Ability	0.44	189.06	1	20.21***
	Memory Capacity	0.03	0.08	1	0.01
	Error		9.35	238	
$R^2 = 0.15$					

***$p<0.001$ *$p<0.05$





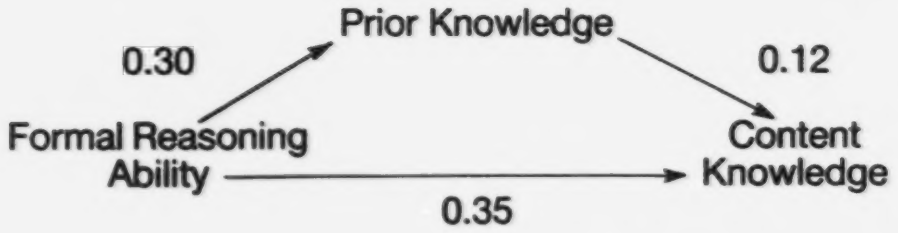


Fig. 1. A path analysis for hypothesized relationships between chemistry achievement and two cognitive predictor variables.